Spin and Deflection Measurements of Microwave-Driven Sails

John Ziemer

Jet Propulsion Laboratory

James Benford, Microwave Sciences, Inc.

Gregory Benford, Abbenford, Inc.

Timothy Knowles, Energy Science Laboratories, Inc.

Keith Goodfellow, Raul Perez, and Henry Harris

Jet Propulsion Laboratory

Overview

- Spin Measurements

  Spinning sails is useful for stability and deployment

  – Sail material properties: Type A

  – Testing facility and procedure

  – Results: movies and coupling coefficient measurements

- Pendulum Deflection Measurements

  Measure deflection vs. power to investigate acceleration mechanism

  – Sail material properties: Type B

  – Results: movies and deflection as as function of power

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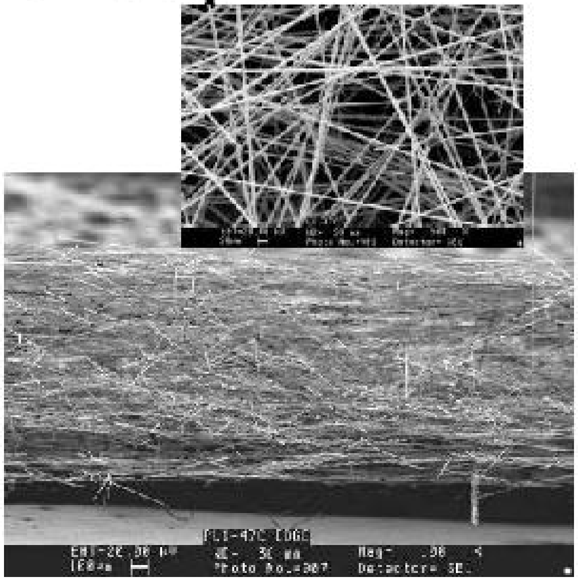
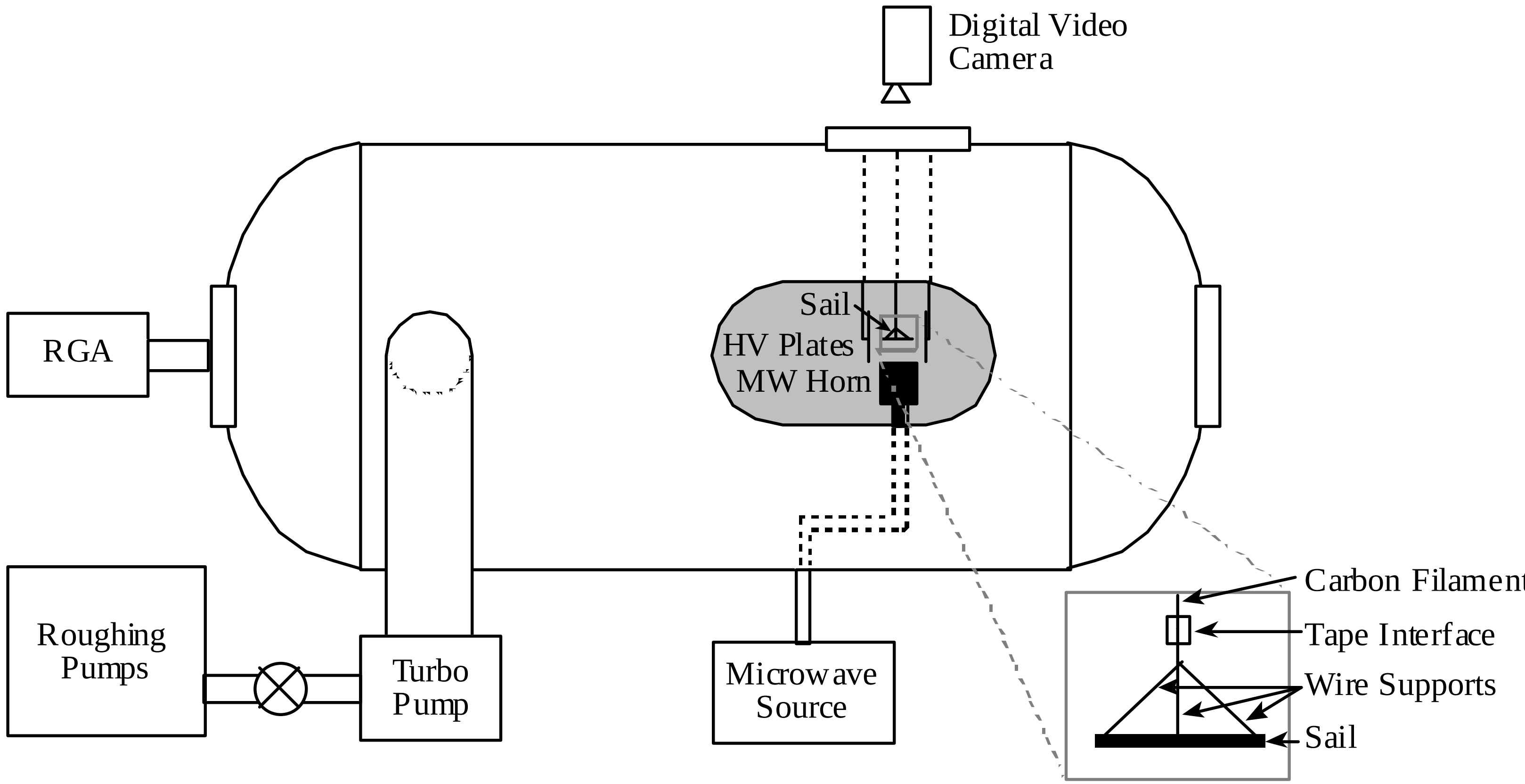
Carbon Sail Material Type A

ESLI MW-Sail Concept*



- 3D Architecture
  - Thick porous sandwich
    - Surface net + truss core
    - Stiff and lightweight
- Carbon-carbon materials
  - Carbon-fiber, carbon nodes
    - Strong, conductive, creep-resistant
    - High temperature capability

Microwave Sail Test Facility



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Spin Movies

Aluminum Disk with slot
Power: 100 W

QuickTime™ and a
Sorenson Video decompressor
are needed to see this picture.

Carbon Cone, no slot
Power: 50 W

QuickTime™ and a
Sorenson Video decompressor
are needed to see this picture.

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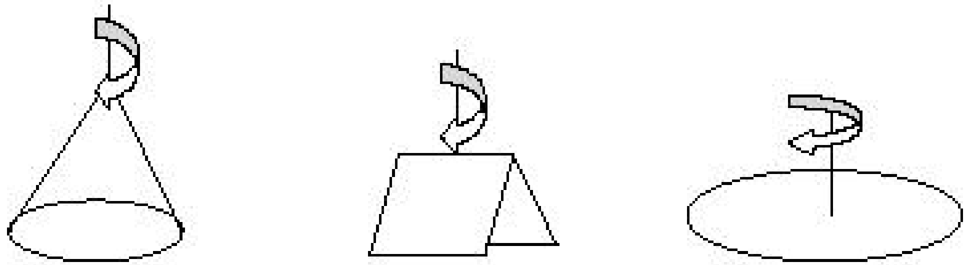
Results from Spin Experiments



$$I_q \ddot{q} = T_{spring} + T_{damping} + T_{applied}$$
$$= -k_q q - n\dot{q} + aI_q P$$

$$a = \frac{q_{steady} w_n^2}{P} \qquad C^* = apnI_q = \frac{pnq_{steady} k_q}{P}$$

Sail Shape and Material	Radial cut?	Does it Spin?	Coupling C*
Al "roof"	no	yes	0.03
Al disk	no	no	
Al disk	yes	Yes	3×10^{-4}
Al cone	no	no	
Al cone	yes	yes	0.11
C disk	no	yes, erratic	
C cone	no	yes	0.10

Carbon Sail Pendulum

Pendulum is made of type B material:
fibers are orientated along arm length

- DC sheet resistance:
  - ~1Ω/square
- Mass: 0.093 g
- Emissivity: > 0.7

17.5 cm

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[illegible]

Carbon Pendulum Movies

- **Power varied from 4-14.5 kW in 10 second trials**
- **Position determined by digital video processing software**

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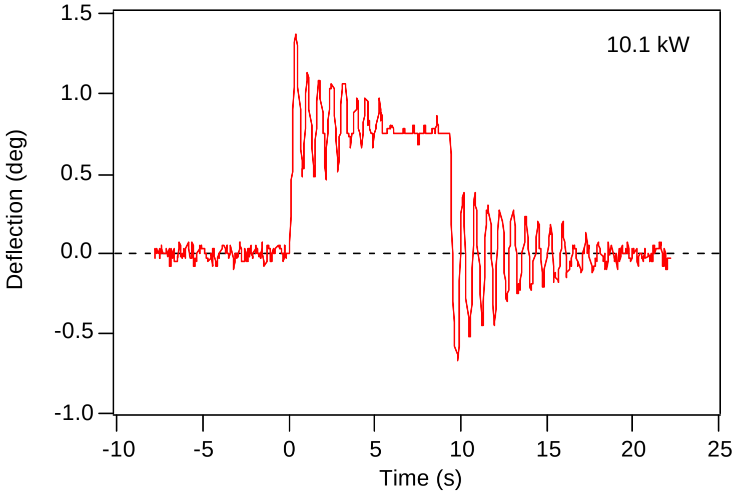
Deflection Measurements

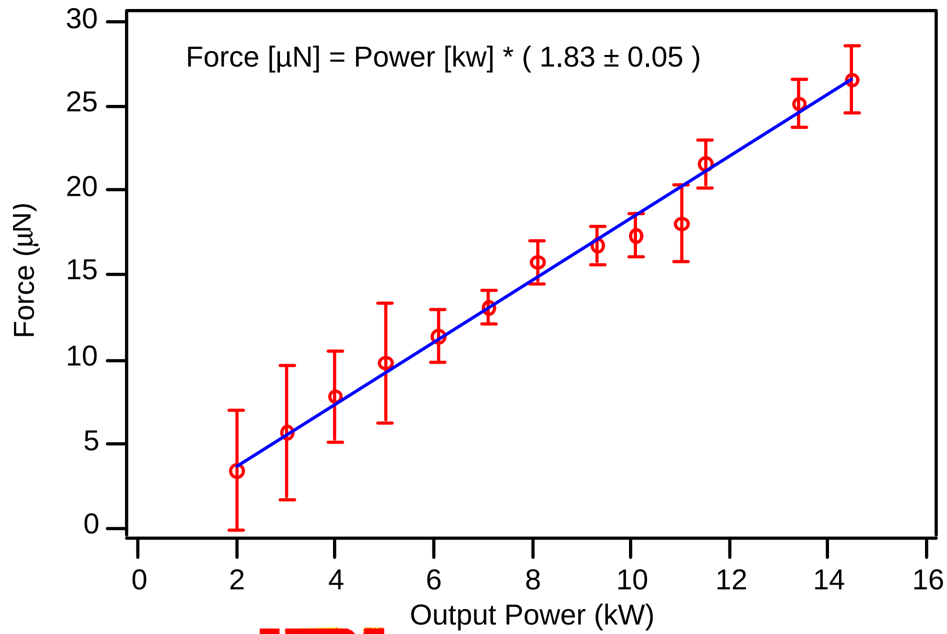


$$F = \frac{\ell_{cm}}{\ell_{cf}} mg \sin q$$

$$F_{photon} = \frac{h_{power} P}{c} (2 - a) \cos^2 q$$

Position measurement limited by single pixel resolution

Deflection is nearly linear with power



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Conclusions

Spin Measurements:

- Carbon sail coupling coefficient (efficiency) is about 10%
- Aluminum sails do not spin if they are circularly symmetric
- Disturbing the circular symmetry causes aluminum sails to spin
- Shape is important for sails when diameter is on the order of the wavelength
- General behavior of sails under electrodynamic torques did fit expectations

Deflection Measurements:

- Type B material is highly reflective with good thermal conductivity
- Pendulum experiments showed a linear deflection with input power
- Pendulum behaves as expected for 25-30% of beam power incident on sail

Acceleration is Temperature Limited

Microwave Sail Acceleration

- T-limited acceleration, a, given by

$$\alpha I = 2\varepsilon\sigma_{SB} T^4 \qquad \alpha = 4R/Z_0$$

$$a \approx \frac{2I}{c\sigma} \approx \frac{4\sigma_{SB}}{c}\frac{\varepsilon}{\alpha}\frac{T^4}{\sigma} \approx \frac{Z_0\sigma_{SB}}{c}\frac{\varepsilon}{R}\frac{T^4}{\sigma}$$

I = intensity (W/m2)
σ = areal mass (kg/m2)
R = sheet resistance (Ω)
ε = emissivity
α = absorptivity
Z_0 = 377 Ω

- Carbon with high specific conductivity best

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